Armed Services Technical Information Agency

Because of our limited supply, you are requested to return this copy WHEN IT HAS SERVED YOUR PURPOSE so that it may be made available to other requesters. Your cooperation will be appreciated.
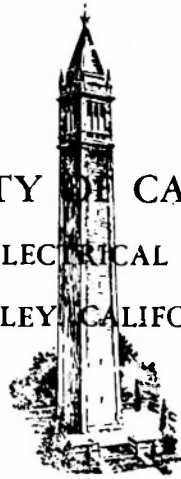
AD 41256

UNCLASSIFIED

UNIVERSITY OF CALIFORNIA

DIVISION OF ELECTRICAL ENGINEERING

BERKELEY CALIFORNIA

ELECTRONICS RESEARCH LABORATORY

QUARTERLY PROGRESS REPORT
1 JULY 1953–30. SEPTEMBER 1953

ELECTRONICS RESEARCH LABORATORY

Division of Electrical Engineering
University of California
Berkeley, California

Quarterly Progress Report
Series 60, Progress Report No. 2
July 1 - Sept. 30, 1953

Oct. 15, 1953

Prepared by:

D. H. Goodman
D. H. Goodman

J. D. Axtell, Jr.
J.D. Axtell, Jr.

Approved by:

J. R. Whinnery
J.R. Whinnery

PERSONNEL

Administration:

J.R. Whinnery, Vice Chairman,
 Division of Electrical Engineering;
 in charge of the Electronics Re-
 search Laboratory

J.D. Axtell, Jr.
 Administrative Engineer

D.H. Goodman, Supervising
 Engineer, Contracts
 AF33(616)-495 and W33(038)-ac16649

Faculty Advisory Committee:

P.L. Morton, Chairman,
 Division of Electrical
 Engineering

S. Silver+
D.H. Sloan
O.J. Smith
J.R. Whinnery, Vice Chair-
 man, Division of Electrical
 Engineering

Research Staff:

Faculty:
 D.J. Angelakos
 L.J. Black
 G.L. Matthaei
 L.E. Reukema
 S. Silver+
 D.H. Sloan
 J.R. Whinnery

Engineers, Graduate Students and Undergraduate Assistants:

R. Allison
*G.A. Becker
R.W. Bickmore
*F.D. Clapp
M.R. Currie
*A.L. Gardner
D.H. Goodman
G. Held
R.L. Hess
C.W. Hartman
J.S. Honda
W. Houweling
J.B. Humfeld
G. Jeranson
H. A. Judy
Z Kaprielian
G. Kelley
W.H. Kummer
W.M. Mueller
J. Mirushian
R.S. Nelson
R. Plonsey
A. Serang
S. Solomon
G.K. Tajima
H. Unz
W.H. Watson
C.R. White
S.V. Yadavalli

Secretaries:

A. Simmons
V. Ulrich

Draftsman and Technicians:

T.E. Bowman
K.D. Kerr
J.P. Meade

+ On sabbatical leave

*Also carries some technical
 supervisory responsibility

FORWARD

During the formative period of the Electronics Research Laboratory at the University of California, it was planned that, as soon as feasible, a joint Progress Report would be issued. This is the second such joint report. The work described in this report is that of two of the groups of the Laboratory: the Antenna Group, supported by the Office of Naval Research under Contract Number N7-onr-29529, and the Microwave Tube Group, supported by the Wright Air Development Center under Contracts W33(038)-ac 16649 and AF33(616)-495. It is planned that future reports will include non-contract sponsored research studies also being carried on in the laboratory. To those who have received reports from either of these groups in the past, it should be pointed out that a continuity of content of the Progress Report material exists, but it was necessary to change the numbering system. All reports will now be issued as E.R.L. reports, Series No. 60, with Progress Reports starting with Number 1 and Technical Reports starting with Number 100.

TABLE OF CONTENTS

I. BEAM TYPE MICROWAVE TUBES

Contract Numbers
W33(030)-ac-16649
AF33(616)-495

Prof. J.R. Whinnery
G. A. Becker
M. R. Currie
R. L. Hess

S. S. Solomon
W. H. Watson
S. V. Yadavalli

1.1 Backward-Wave Interaction Studies

The investigation initially concerned itself with the tape helix
as a periodic propagating structure. In particular, its suitability as
a circuit for the backward wave oscillator (B.W.O.) was examined. Based
on the work of Sensiper[1], calculations of the impedance characteristics
of the principal backward wave harmonic were made[2], and it was con-
cluded that the tape helix is an excellent interaction circuit for the
B.W.O. if the helix and electron beam are suitably designed.

A design, based on these calculations, was worked out in the first
quarter of this year. The tube was constructed and placed into operation
in the second quarter. Results of initial tests were described in the
last progress report. A moding phenomenon occurred in the transition
from the amplifying to the oscillating regimes, and it was felt that
this was caused primarily by poor matching conditions at the transition
between the helical and coaxial transmission lines. Therefore it was
decided to study the matching problem more closely before proceeding
with an accumulation of more data on the operating characteristics of
the tube itself.

During the last quarter, considerable effort has been expended in
improving the coaxial-helix transition. For helices of moderate size
the concept of gradual transition from coaxial to strip transmission

1. Sensiper, S., "Electromagnetic Wave Propagation on Helical
Conductors", Ph.D. Dissertation, MIT., 1951.

2. Currie, M.R., "Notes on the Impedance Characteristics of Modes
on Helix", Unpublished Report, E.R.L., University of California.

line has been found exceedingly usefu in designing satisfactory matching sections. For helices in air on the test bench, voltage standing wave ratios less than 1.5 over a three to one frequency bandwidth have been obtained.

In practice, the transition must be made through glass and the coaxial line must be sharply bent so that it can come out of the focussing solenoid. These factors complicate the design problem and reduce the quality of the match. However, a good match (700-2100Mc) has been developed by bringing the helix out tangential to the glass envelope and using a flat glass bead to seal in the tungsten lead. This arrangement is being ruggedized at the present time and will probably be employed in the modified design of the B.W.O.

A new tape helix using molybdenum has been wound and will be built into the modified B.W.O. design. The tube will be operated at lower values of (ka) than was the original tube in order to take advantage of good matching below (ka) = 0.4 and so that a somewhat smaller range of beam voltage will be required for a given bandwidth. Universal helix-design curves have been constructed and the data furnished by the modified tube will check the curves over a new range.

In addition to the effort described thus far, the backward wave interaction study is proceeding along two other lines:

First, the question of interaction with a transverse rather than a longitudinal r.f. field is being considered. Until now, strong magnetic focussing fields have been used with backward wave oscillators so that motion of the beam in the transverse direction is greatly inhibited. However, it is anticipated that effort in the future will be directed towards minimizing the focussing field with its weight, power requirements, etc. Therefore it becomes pertinent to investigate interaction with transverse fields and how it affects B.W.O. operation. Some calculations have shown that, for a helical interaction structure and in the ranges of parameters usually encountered, the transverse field can become comparable with the longitudinal field. It is apparent that an analysis which takes into account both interactions simultaneously (with a finite magnetic field) will be extremely complicated. Thus, it has been decided to attempt to maximize transverse

- 2 -

interaction and study its dependence on magnetic field. Pierce[3] has considered the question briefly for forward wave amplifiers, and it is felt that application to the case of backward wave interaction will yield simple results. Furthermore, a tentative design is being considered for a transverse-field B.W.O. The contemplated interaction structure is a tape helix concentric with a conducting rod. Approximate calculations are being started to determine what transverse-field impedances can be expected for such a circuit. If these calculations look optimistic, an experimental tube will be constructed.

Another phase of the general investigation is being devoted to a study of backward wave interaction with an initial current and/or velocity modulation of the electron beam. More specifically, the use of a backward wave circuit as a signal launcher and as a catcher is being considered. It is felt that such a study will lead to results of interest to workers in this general field and could lead to application in special voltage-tunable amplifiers.

<div align="right">M.R. Currie</div>

1.2 Space Charge Waves in a Finite Magnetic Field

A two dimensional study of space charge waves in the presence of two mutually perpendicular uniform electric and magnetic fields E_o and H_o respectively such that $E_o = \mu v_o H_o$ has been outlined in previous reports. The differential equations derived previously have been solved by treating the special case when a sheet beam of electrons extends to a height "b" in a region bounded at a height "a" by the slow wave structure formed by slitting the infinite plane conductors with many parallel cuts, making an angle $\left(\frac{\pi}{2} - \theta\right)$ with the direction of propagation as shown in Fig. 1. The two following problems are considered: (a) Uniform electric field along the x axis and all derivatives with respect to the x axis are made zero:

---

3. Pierce, J.R., "Traveling Wave Tubes", D. Van Nostrand Co., Inc., New York, 1950.

slow wave structure

2b   2a

Electron Beam

Side View

θ

cut

Top View
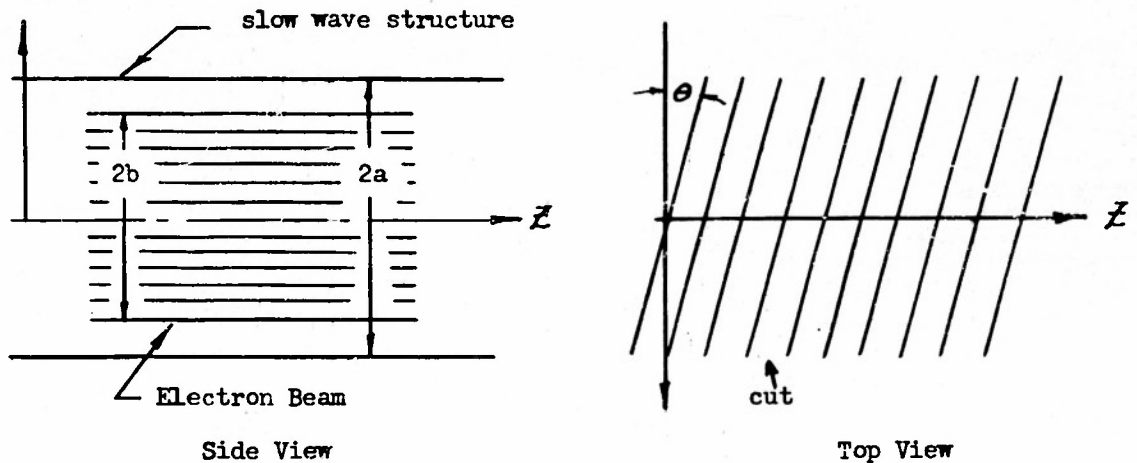
Fig. 1

In this case it can be easily shown that when the d-c. beam velocity v_o is much smaller than the velocity of light then the coupling between the TE and TM modes is of the order of v_o^2/c^2 and therefore may be neglected. When this is done it can be shown, neglecting a quantity of the order of $\frac{v^2}{c^2}$, that this case reduces to that of a beam in the presence of a longitudinal finite focussing magnetic field.

(b) Uniform electric field along the x axis and all derivatives with respect to the y coordinate are made zero: We regret that an error occurred in a boundary value solution of this problem described in a previous report. Actually in this case which is the basic model of the magnetron amplifier, the TE and TM modes separate. The gain is obtained when the beam velocity is much smaller then the velocity of light from interaction between the transverse component of the TM mode and the beam. The TE and TM modes are coupled at the circuit. The amount o f the gain is found to be given very approximately, when the uniform magnetic field is large enough and the beam fills the space up to a height "a" in Fig. 1,, by the following expression:

- 4 -

$$\alpha = \frac{\omega\,\omega_0}{2v\,\sqrt{\omega\,\omega_c}} \quad \text{nepers/meter}$$

where $\quad \omega_0 = \dfrac{e\rho_0}{\epsilon m_0} \equiv$ plasma frequency

$$\omega_c = \frac{\mu H_0 e}{m_0} \equiv \text{cyclotron frequency}$$

$\omega \equiv$ operating frequency

$v_0 =$ electron velocity

This amount of gain is seen to be somewhat less than that obtained from the conventional traveling wave tube which is known to have a gain given by:

$$\alpha = \frac{\sqrt{3}}{4}\,\frac{\omega}{v_0}\left(\frac{\omega_0}{\omega}\right)^{\frac{1}{3}} \quad \text{nepers/meter}$$

On the experimental side a d-c model for the contemplated magnetron traveling wave amplifier has been built and is undergoing tests to determine d-c beam transmission. Also a zigzag plane structure as described in a previous report suitable for a cold test has been built successfully using photo-etching techniques. From our model we could ascertain that the relative field strength remains fairly constant along the width of the zigzag structure. The same is true of the phase velocity up to frequencies where the width of the structure becomes of the order of a quarter wave length at the operating frequency.

If the d-c beam tests are successful, the zigzag circuit will be placed in the tube to make the contemplated traveling wave magnetron.

On the theoretical side we are to investigate the possibility of growing backward waves in the magnetron traveling wave tube using our method of analysis as an approach to the investigation.

S. Solomon

1.3 Helix Impedance Measurements

The object of this investigation is to study the impedance character-
istics of a junction between a coaxial and a helical transmission line. In
particular, it is desired to define a suitable characteristic impedance for
the helix, and to determine the effect of the helix and junction parameters
upon the input impedance as seen by the coaxial line. The primary interest
is with right angle transitions from a coaxial line to a helix with an ex-
ternal shield. This type of transition is of importance due to its applica-
tions in traveling-wave tubes.

As a first approach to this problem, it was decided to determine an
equivalent circuit for the discontinuity in the fields at the junction of
the two lines. During the last quarter considerable time was spent in work-
ing out a satisfactory method of determining this equivalent circuit. The
most satisfactory method was found to be one which was outlined by Storer,
Sheingold and Stein.[1] Using this method, the input impedance is measured
as a function of the position of a movable short in the output line. Then,
by a graphical analysis, we are able to determine the scattering matrix of
the junction, where

$$ S = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} $$

The experimental setup used is shown in Fig. 1. The shorting medium
used was mercury, and the position of the short was moved by raising or
lowering a vertical traverse system. The input impedance was measured by
use of VSWR and phase measurements made on a slotted line.

The scattering matrix, as determined by a graphical analysis of the
experimental data, is transferred to the reference terminals T_1 and T_2 by
use of the suitable phase factor. The impedance matrix can be obtained from
the expression.

$$ Z = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = \begin{pmatrix} \sqrt{Z_{01}} & 0 \\ 0 & \sqrt{Z_{02}} \end{pmatrix} (I - S)(I + S) \begin{pmatrix} \sqrt{Z_{01}} & 0 \\ 0 & \sqrt{Z_{02}} \end{pmatrix} $$

Where Z_{01} and Z_{02}
are the character-
istic impedances of
the input and output
lines respectively.

---

1. Storer, Sheingold and Stein, "A Simple Graphical Analysis of a Two Port
    Waveguide Junction", Proc. I.R.E. Vol. 41, No. 8, pp. 1004-1013, Aug. 1953.

Type (N) Fitting

Brass

air

1 3/8"

air

3 1/4"

5/8"

T_2

Test Junction (Cross Section)

Helix

Helix Spec.
6 - turns/inch
.75" inside dia-
meter wound of
1/16" copper wire

Top View

1000~ MOD

VSWR Meter

RF GEN

Slotted Line

Test Junction

Mercury Shorting System
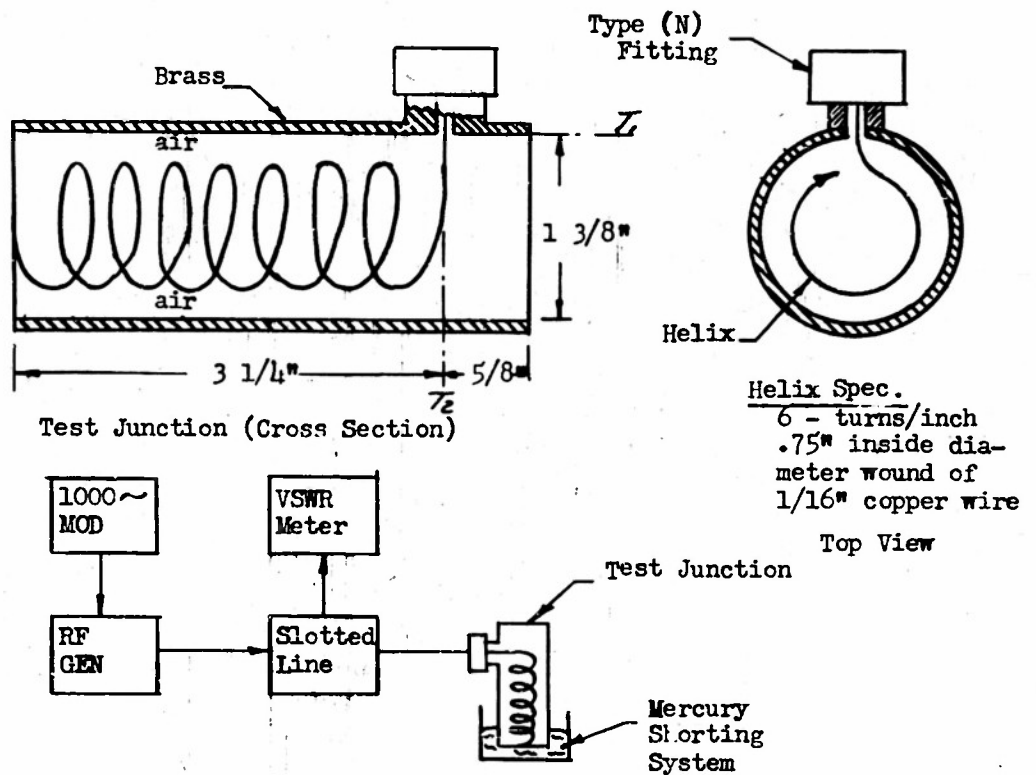
Fig. 1

Having the impedance matrix, we are able to construct the equivalent circuit
for the discontinuity at the junction as shown

$$ Z = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = \begin{pmatrix} \sqrt{Z_{01}} & 0 \\ 0 & \sqrt{Z_{02}} \end{pmatrix} (I - S)^{-1} (I + S) \begin{pmatrix} \sqrt{Z_{01}} & 0 \\ 0 & \sqrt{Z_{02}} \end{pmatrix} $$

T_1 — $Z_{11} - Z_{12}$ — Z_{12} — $Z_{22} - Z_{12}$ — T_2

Fig. 2
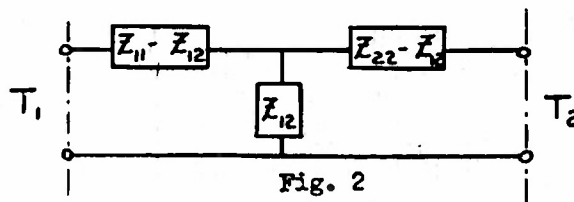
It is proposed to determine this equivalent circuit for various helix and
junction dimensions in the L and S band of frequencies. It is felt that
an analysis of the variation in this equivalent circuit, as a function of
the various parameters, will lead to a better understanding of this type of
junction.

In the future, it is proposed to investigate the effect of a surface
modification of the input circuit. This modification would possibly take the

form of a thin dielectric coating on the center conductor of the coaxial line, in the region of the discontinuity.[1]

<div align="right">W.H. Watson</div>

1.4 Large Signal Study

For experimental study of large-signal phenomena in traveling wave interaction it would be convenient to have a tube in which the traveling wave circuit was external to the vacuum envelope enclosing the electron beam, thereby facilitating measurements and changes in design. This arrangement would entail the interposition of a glass wall between the beam and circuit and a means for draining accumulated electron charge from the internal wall of the tube. A conductive coating sufficient for this purpose, however, must not completely short out interaction between the beam and circuit. A coating of perhaps a few thousand ohms per square appears desirable. Experiments have shown that metallic coatings of oxidized stannous chloride can be applied to the inside wall of glass tubing to give this conductivity.

A series of experiments is planned in order to observe the effect of the glass envelope on traveling wave amplification. A series of helix-type tubes is being fabricated, each with the same helix dimensions, but with the coated or uncoated glass envelope placed at various positions inside and outside the circuit. It is hoped in this way to determine the feasibility of obtaining useful experimental information from tubes with external circuits.

<div align="right">R.L. Hess</div>

1.5 Electron Beam Focusing Studies

The possibility of using electrostatic focusing in beam type tubes is being investigated. In particular consideration is being given to the possibility of using the lenses formed by the drift tubes of a "velocity-jump" amplifier to focus the electron beam.

<div align="right">W.M. Mueller</div>

---

1. T.E. Roberts Jr., "An Experimental Investigation of the Single Wire Line", Cruft Lab, Harvard Univ., Technical Rept. No. 139, Feb. 1,1952.

1.6 Noise in Electron Streams and Vacuum Tubes

Since Dr. Yadavalli has left this laboratory for work at the General Electric Company, it seems desirable to summarize the purposes and results of the noise studies undertaken here for the last two years. Convection current noise in an accelerated electron stream was measured at large transit angles by means of a model in which transit angles up to 4π radians could be obtained at a relatively low frequency (70 Mc/sec.) to simplify measurement of noise. The beam was about 1/4 inch in diameter and was focussed by Pierce-type electrodes. Noise convection current was sampled by means of closely spaced grids at a fixed position along the stream, and transit angle was varied primarily by changing the beam potential, though checks of points were made both at 35 and 70 Mc/sec.

The absolute measurement of noise showed good agreement at low transit angles with the space-charge reduced shot noise calculated for the stream. At larger transit angles, the noise current increased, following the curve calculated from the single-valued velocity theory of Rack and Peterson closely, but was about 2 decibels below the calculated curve up to largest transit angle taken, 4π radians. The last six months have been spent in attempting to explain the rather small difference. One possibility is that it is due to the actual multivalued characteristic of the noise, and an integral equation governing noise in an accelerated stream was developed, but so far it has been possible to solve it only for special cases. Another good possibility is that the difference comes from the finite diameter of the beam, as the comparison was with the theory for a region of infinite width. Step-by-step calculations were then made, considering the finite beam diameter by means of an effective plasma frequency, and better agreement was obtained in the long transit-time region, but worse in the short transit-time region. A third possibility is that the decrease in noise comes from a divergence of the beam, since such a divergence has been shown to decrease noise convection current. Other possibilities have been considered but not analyzed.

Measurements were made with the first grid both negative and positive, and agreement between the two, accounting for the partition noise in the positive grid case, was excellent. Statistical theory was also applied to study the correlation between velocity and current fluctuations in a beam, and it was concluded that the two are uncorrelated at the cathode, but may have cross-correlation terms through the action at the potential minimum at large transit angles. Recent measurements have also been made on a tube with a

drift region following the accelerating region, but interpretations of these results were not completed.

The noise work will be suspended until another graduate student is found who wishes to work in this field. More details on all of the above are contained in the following reports and papers prepared by S. V. Yadavalli which have been presented at technical society meetings or have been accepted for publication in scientific journals:

"Tube Noise Under Large Transit Time Condition."
> Electronics Research Laboratory Report Series #1, Issue #61

"On the Correlation between Velocity and Current Fluctuation in Shot Noise."
> Electronics Research Laboratory Report Series #1, Issue #64

"On Some Effects of Velocity Distribution is Electron Streams."
> Accepted for Publication in Quarterly of Applied Mathematics.

"Tube Noise Under Large Transit Time Conditions."
> Accepted for publication in Journal of Applied Physics.

"Convection Current Noise in Accelerated Regions-Theoretical and Experimental Results."
> Presented at Conference on Electron Tubes, Stanford University, June 20, 1953.

"Convection Current Noise – Theory and Experiment."
> Presented at I. R. E. Western Convention, August 19, 1953.

II. HIGH POWER MICROWAVE TUBES

Prof. D.H. Sloan   W.M. Mueller
A.L. Gardner   Wm. Houweling
D.H. Goodman

2.1 Model S-7 10.7 Cm. Resnatron

Fourth Assembly

At the time of the previous report a new cathode ring had been mounted
and the new grid consisting of 480 radial wires was nearing completion. Be-
fore final assembly a special fixture was made in which the mounted annular
cathode ring could be firmly supported in order to allow a finishing cut to
be taken on its surface. Prior to this operation the cathode ring was strain-
relieved by running it at operating temperatures in a vacuum. This technique
considerably reduced the tolerance within which the grid-cathode spacing
could be held.

During the bakeout following the third assembly of the tube two cracks
developed in the glass envelope. They were readily sealed with glyptal
and no inconvenience resulted at that time. When the tube was being bolted
together at the time of the final fourth assembly, however, one crack opened
much wider and extended itself. Although a bakeout was subsequently complet-
ed and a good vacuum was obtained, adequate tests to evaluate the grid per-
formance were prevented by two factors:

a) the emission rapidly diminished, presumably as a result of poison-
ing by products released from traces of glyptal present during bakeout and

b) traces of carbon in the crack provided a leakage path that caused
sparking when the anode voltage was greater than about half its rated value.

Rather than spend effort to put new glass on the original anode it was
considered advisable to await the completion of the new anode which was de-

scribed in the previous report. Besides the improved electrical features this anode assembly is constructed to give the glass envelope more protection against differential expansion or mechanical distortion of the metal flanges between which the copper gasket is clamped. This construction is now nearing completion.

A.L. Gardner

2.2 Field Emission Tube

The field emission tube is designed to investigate the possibility of obtaining a density modulated electron stream by controlling the number of electrons actually leaving the metal cathode, rather than realizing the modulation through a velocity modulation and a drift region or by control of a space charge. Due to the exponential nature of the field emission it may be possible to achieve rather large ratios of electron densities along the stream.

During the past quarter, in order to facilitate r-f measurements on this tube, a second pick-up loop was installed in the tube. Prior to making any r-f measurements, it was felt that some of the d-c characteristics of the emitter should be known. Figure 1 is typical of the emission characteristics that are obtained from a field emitter.

As a result of the fairly reproducible and reliable emission that has been obtained from the emitter in this tube under these d-c conditions it was felt that it would be expedient at this point to make some r-f measurements, although the levels of power that are to be expected are extremely low. An attempt was made to measure the change in output as a function of anode current by measuring the power transferred through the tube into a bolometer bridge. Since this requires the measurement of a very small change of a fairly large quantity, it was not possible to obtain conclusive results in this manner. As an alternative, a system is being devised whereby the d-c voltage which is applied to the tube will be modulated by a square wave, and the "d-c" component of the r-f which is transmitted through the cavity with no modulation will be eliminated from the detection system. In this way only the change in output will be measured since it occurs at a
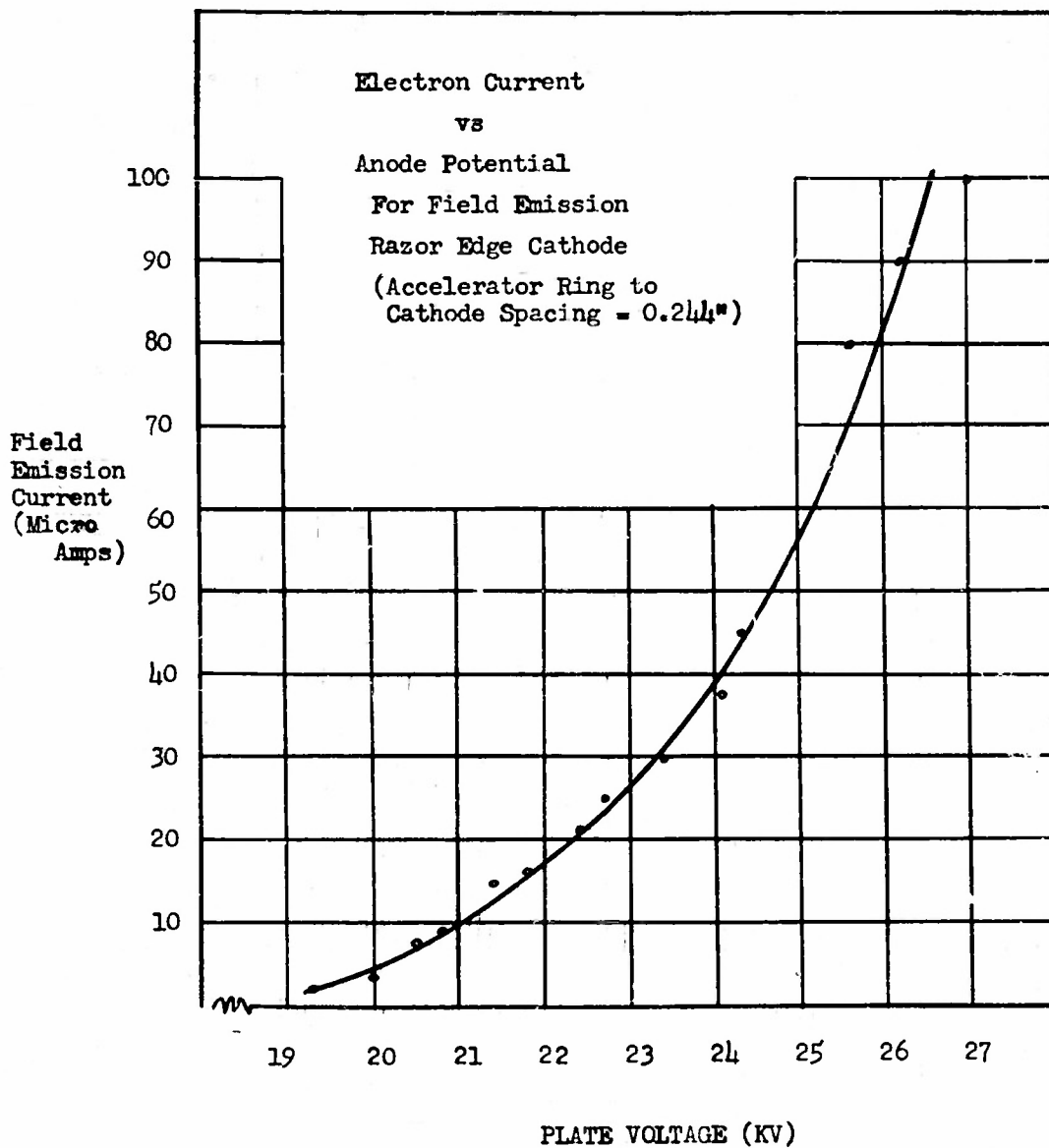
Fig. 1

known periodic rate. This will allow the use of high gain amplifiers and should permit the detection of quite small interactions.

A schematic of the system to be employed in these measurements is shown in figure 2. This equipment is now essentially complete, and during the next quarter further measurements will be made using this new system. As soon

Fig. 2

as the information available from this type of detection system is exhausted, pulse type measurements will be made. The use of pulse techniques has been postponed due to the possibility of arc formation and the resulting destruction of the emitter.

D.H. Goodman

III. HIGH DENSITY CATHODE STUDIES

Contract Numbers
AF33(038)-ac-16649
AF33(616)-495

Prof. D.H. Sloan
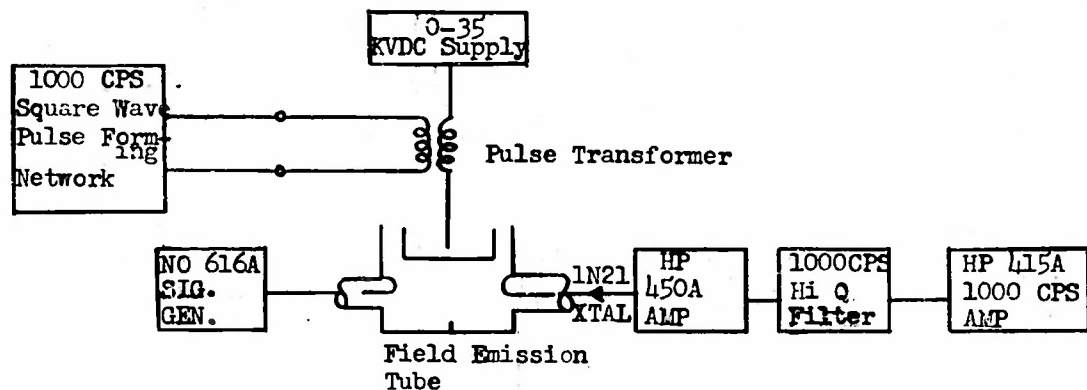R.S. Nelson
C.R. White

3.1 Arc-Cathode Studies

The tin-arc tube has been operated successfully for a total of 46 hours with a design of electrodes that returns condensed metal vapor directly to the active area of the cathode pool. A cylinder of vycor glass, 2 inches inside diameter, acts as an insulating perimeter for the hot spot on the surface of the cathode and acts as a retaining wall for the vapor and condensate. At the end of the series of runs the electrodes and vycor glass showed no noticeable deterioration.

On Aug. 18, 1953 the first experiments were conducted to extract electrons from the arc-discharge region into the high vacuum region. A hole drilled into the side wall of the arc-discharge anode was used to form the area from which electrons could be extracted. A plate of molybdenum was used as an anode for the first trials; later a graphite anode of a more convenient shape was substituted. With application of plate voltages as high as 13 kv. d-c current densities of 0.8 amperes/cm^2 were obtained from a 1/4-inch extraction hole with an arc-discharge anode current of 45 amperes. In order to obtain a larger cathode area and increase the number of electrons passing into the high vacuum region, additional holes will be placed in the arc-discharge anode. Increased values of arc current are capable of increasing the density of electrons available; other design refinements are also expected to increase the available electron supply. A water cooled anode is being installed to provide suitable heat dissipation.

A second graphite electrode was placed between the first graphite anode and the extraction hole. The new structure contained a hole to pass electrons and acted as a control grid. This triode, using an arc-cathode, was connected as a shunt-fed Hartley oscillator and continuous oscillations were obtained at the tank-circuit frequency of 6.2 mc. R-f power capable of exciting a 40-watt florescent lamp when held within a foot of the tank coil was obtained

with 200 watts of input power (approximately 30ma. at 6.8 kv). Because of the high current density at the anode, water cooling will facilitate higher voltage operation.

T.E. Bowman
C.R. White

IV. SLOT ANTENNAS

Contract Number

N7-onr-29529

Prof. L. J. Black   R. W. Bickmore
Prof. L. E. Reukema   G. K. Tajima

4.1 Resonant Circular Slots in Plane Surfaces

Summary of Previous Work

This problem, which consisted of an analytical determination of the distribution, amplitude and phase of the electric field in a concentric array of annular slots necessary to produce a specified far-zone space pattern, has been completed.

Included in the study were various methods of producing the required excitation in the slots, once this excitation has been theoretically determined. The methods considered include circular waveguide excitation, TE_{om} cavity excitation (by means of probes) and excitation by means of selective dielectric filling of a coaxial line.

Experimental antennas which have been built and tested are:

1) Circular pencil-beam broadside array linearly polarized.
2) Circular pencil-beam broadside array circularly polarized.
3) Quasi-isotropic radiator with phase equal to azimuthal angle.
4) Cardioid pattern radiator.
5) Equivalent annular slot array of a linear "binomial" array.

Current Work

During the present quarter, a report has been prepared covering in detail the entire study outlined above. This report is nearly ready to issue.

R. W. Bickmore

4.2 Non-Resonant Circular Slots in Various Ground Plane Shapes

Summary of Previous Work

The principal problem in this study is the determination of the admittance characteristics of circular slot antennas in conducting surfaces of various forms.

The admittance of a circular slot on a spherical surface has been measured, using a hemispher 17 cm. in diameter, over a frequency range from 300 to 1500 mc. Two methods of measurement were used. For the upper part of the frequency range, the measurement of the admittance was made in the radially-directed biconical line leading to the slot, by the use of a fixed probe. The SWR was obtained from this probe by using a Chipman line as a variable reactance termination on the input end (at the axis of rotational symmetry) of the biconical line. The position of the voltage minimum was found by varying the frequency, causing the voltage minimum to be swept past the probe position. The signal may be fed into the system almost anywhere, but most conveniently at the shorted end of the Chipman line. The results so obtained are free of the effects of rapid admittance changes. For the lower frequencies, it was necessary to use the Chipman line in the conventional manner. The measured results agree fairly well with the computed admittance, with the first method yielding superior results.

The formal solution for the admittance of a biconical horn has been obtained by a mode expansion method.

Measurements have been made on the junction between a coaxial line and a radial line. An equivalent circuit representation of the junction was developed which reduced the usual three unknown parameters to two, even though the junction was non-symmetrical, by proper choice of the input terminal position. This information was required for the measurements on the circular-disk antenna.

Current Work

An alternative solution for the admittance of a biconical horn was obtained by means of a variational principle. The results have a form in which the admittance can be decomposed into two parts; an admittance of the biconical horn with a spherical cap (i.e., the spherical antenna), plus

a correction term due to the removal of the spherical cap. Since the spherical antenna admittance has been computed and measured previously, there remains only the task of computing the correction term. This computation is partially completed. However, sufficiently-rapid convergence is not yet assured for all values of the parameters. A cone is being constructed for use in making measurements on the biconical horn.

The equivalent-circuit constants of the junction between the coaxial and radial lines have been computed from the measurements. It appears highly desirable to obtain these constants by a theoretical method.

Measurements were made of the admittance of a circular plate parallel to a ground plane, and fed at the center of the plate. The admittance referred to the periphery of the plate was obtained and comparison was made with the results of several approximately similar forms of antennas. The theoretical admittance is to be obtained by a perturbation of the results obtained for the biconical horn.

C. K. Tajima

V. MULTI-MODE STUDIES

Contract Number
N7-onr-29529
Prof. S. Silver+
Prof. J. R. Whinnery
G. Held
W. H. Kummer

5.1 Multi-Mode Excited Slots

Summary of Previous Work

This is a study of narrow half-wave slots at various positions in the wall of rectangular waveguide which supports free propagation of the TE_{10} and TE_{20} modes. Instrumentation has been a large part of the research, and means have been developed for the generation, detection, and measurement of the separate modes in the waveguide.

The impedance and mode-coupling characteristics of longitudinal and transverse half-wave slots in the broad face of the waveguide have been investigated, at constant frequency, as a function of slot position and of slot width. The properties of single slots have been used as a basis for the design of simple arrays.

The experimental setup for measuring slot patterns was designed so that the two-mode waveguide suffered no discontinuities or bends. All the patterns for the single slot at different positions had identical envelopes, the amplitudes being different due to different coupling between guide modes and slot. The patterns were identical to those of a half-wave dipole.

The radiation pattern for a two-slot array has been computed and measured. The measured values differed somewhat from the computed values, and there was some lack of symmetry in the pattern as received in the TE_{10} and TE_{20} arms. The discrepancy was attributed to the close tolerances required in machining the slots. Matrix representation of the slot obstacle was employed to determine the error introduced by a finite amount of unwanted cross-coupling in the impedance-measuring system. The impedance scattering coefficients for the two-slot array was measured; and there was found a lack of symmetry due to machining.

W. H. Kummer

Current Work

During the present quarter, the work has been entirely on the preparation of a report covering in detail the study outlined above.

+ Prof. S. Silver is on sabbatical leave, but is keeping close contact, through correspondence, with all the work begun under his direction.

5.2 Multimode Propagation in Waveguides

Summary of Previous Work

This study is of the propagation of several modes in a waveguide, and of the effect of obstacles and discontinuities in the guide. The representation of the waveguide by a set of transmission lines coupled at the discontinuity has been investigated, and the reciprocity relations of the scattering matrix and the associated impedance matrix for any kind of obstacles (lossless, lossy, or radiating) has been established. An investigation of the completeness of the representation of a general wave in a waveguide by TE and TM modes has been made, and it has been established that, given E_z and H_z, one can uniquely describe the fields completely, in terms of the TE and TM modes.

Since the commonly used expressions for slot impedance obtained from Babinet's principle differ from measured values by 30%, a better approximation was developed which takes into account the difference between the far-zone fields of a slot in an infinite plane and in the wall of a cylindrical waveguide. Green's functions are set up for interior and exterior regions with matching across the slot and separation of the singularity by a method similar to one used for wire antennas. With this correction of the theory, results are in good agreement with experiment.

Current Work

The theory as developed provides a method for the evaluation of the induced sources in a slot. This allows one to compute both the amplitude and distribution of voltage over a longitudinal slot. These are, in general, functions of the exciting field, and of the slot and waveguide geometry. The expressions obtained for a multimode guide are in closed form and readily evaluated numerically. The scattering by a slot in a waveguide allowing free propagation of two modes has been computed and compared with experimental data. The agreement is very good.

This phase of the multimode research is now completed. A report has been prepared and is now being reviewed.

<div style="text-align: right">G. Held</div>

VI. DIFFRACTION, SCATTERING, AND MICROWAVE OPTICS

Contract Number
N7-onr-29529
Prof. L. J. Black
Prof. S. Silver +
Prof. J. R. Whinnery
J. S. Honda
R. Plonsey

6.1   Scattering from a Prolate Spheroid

Summary of Previous Work:

This research is a study of the scattered field from a prolate
spheroid illuminated by an incident wave. The main problem encountered
up to the present has been the instrumentation. Since the scattered
field is very small compared with the incident signal, a null method
has been used to measure the scattered field. For this technique, a
precise balancing mechanism, a frequency-stable signal generator, and
a high power source are required.

A stabilized klystron oscillator has been used to drive a Varian
V-27 two-cavity klystron amplifier, which makes several watts available
at 9375 megacycles.

Current Work

During the period of this report, a balanced microwave bridge
using a magic tee has been used to detect the back-scattered signal.
This system required a very critical balancing mechanism and was highly sen-
sitive to frequency change. A Hewlett-Packard 752A directional coupler,
with large coupling and high directivity, is now used in place of the
magic tee. Analysis and experimental work carried out with this direction-
al coupler indicated that the directional coupler used as a reflectometer
is less frequency sensitive than the magic tee.

However, similarly to the magic tee method, the received back-
scattered signal indicates that multiple scattering is present. Assuming
the main multiple scattering to occur between the scatterer and the horn,

---

+ Prof. S. Silver is on sabbatical leave, but is keeping close contact,
through correspondance, with all the work begun under his
direction.

an analysis of the multiple scattering effect was carried out. The analysis is quite similar to that made by D. D. King.[1]

In the next quarter, the parameters necessary to determine the radar cross-section of two scattering objects – a sphere and a prolate spheroid – will be measured experimentally. If the assumption made about the multiple scattering effect is correct, the radar cross-section of the sphere and prolate spheroid can be measured experimentally.

J. S. Honda

6.2 Beam Shaping Antennas

Summary of previous Work

This is an investigation of the diffraction phenomena of cylindrical reflectors, for the production of shaped beams. The experimental activities to date have primarily been design and testing of a pillbox for use as a line source. A fair amount of time has been spent on this, since the pillbox, in a rough two-dimensional sense, reproduces some of the same problems that will be dealt with in the overall problem. Measured field patterns in the cylindrical zone were found to have both phase and amplitude deviations from the mean that were larger than desirable and an effort has been made to determine the cause of this.

Numerical calculations (using a spiral diagram technique) were made assuming uniform aperture illumination, but taking account of the blocking action of the pillbox feed. As the calculated pattern agreed well with the measured pattern over a considerable range, it was concluded that the predominant aperture effect is from diffraction at the edge of the pillbox and of the feed (i.e. feed blocking). Scattering from the straight sides also contributed somewhat to the irregularity of the pattern.

---

[1] King, Donald D., Measurements at Centimeter Wavelength, D. Van Nostrand Company, Inc., N.Y. pp. 291-294.

Theoretical investigations have also been conducted along lines of getting improved representations for current induced on the reflector surface, thereby improving the far field calculations. To accomplish this, an asymptotic series, the leading term of which is the geometrical optics term, was investigated in the hope that the second term would provide a suitable correction.

Current Work

The present pillbox will definitely be abandoned because of the blocking action of the feed. A double-pillbox antenna has been considered in its place - and it may be possible to convert the present pillbox into a double-pillbox. It is still desired, if possible, to build a parallel plate arrangement to make all measurements in a two-dimensional sense. As soon as the entire scope of this research is laid out, and future needs ascertained, it will be possible to determine if this scheme is practical.

Further investigations into the theoretical problem of pushing the geometrical optics solution down to quasi-optical frequencies continued. No significant progress along these lines has yet been made, and no conclusions as yet drawn as to the usefulness of the asymptotic series method. A method of attack on the problem was adopted through which, by concentrating on simplified geometrical shapes, it may be possible to develop generalizations to the case of arbitrary-shaped reflectors. The simplest shape is the plane reflecting strip, and some time was spent investigating the problem of an incident plane wave on a strip of arbitrary width. It is hoped to do some work on cylindrical-shaped strips, and to combine the theoretical approach with experimental work.

R. Plonsey

VII. DEVELOPMENT OF CARRIER-CONTROLLED-APPROACH COMMUNICATION SYSTEM ANTENNAS

Contract Number
N7-onr-29529

Prof. D. J. Angelakos   R. W. Bickmore
Prof. L. J. Black   F. D. Clapp
Prof. G. L. Matthaei

7.1 Omni-directional Antennas

Testing of the full-scale 225-400mc omni-directional flush-mounted antenna has now been completed. Results obtained from tests made on the 10' x 12' ground plane at this laboratory were erratic and were considered inconclusive because of the size of the ground plane in relation to the frequency. Since no larger ground plane is available here, the antenna was taken to the Navy Electronics Laboratory at San Diego for additional tests. The VSWR vs. frequency curve obtained at NEL for the full-scale model agreed remarkably well with the results obtained on our ground plane for a 2 1/2:1 scale model, except over a small range (about 30 megacycles) in the vicinity of about 375 megacycles. The tests of the full-scale model gave erratic results in this range. This, however, has been traced to leakage of energy in the measuring system.

The table shown below summarizes the electrical performance and size characteristics of this type of antenna. A complete technical report on this work has been prepared and will be issued soon.

Freq. Range MC	Type	Max. VSWR	% of Range having VSWR>2.0 approx	Overall Diam.	Overall Depth	Position in Deck (grd. plane)
225-400	Corrugated Wall	2.5	6%	32"	4"	Flush
225-400	Adjustable Capacity	2.9	50%	30"	4"	Arbitrary
100-156	"	2.4	30%	66"	8 1/2"	"
60-80	"	2.1	6%	100"	12"	"

7.2 Cardioid Pattern Antennas
Flush-mounted Type

The antenna under consideration is a flush-mounted annular slot antenna having cardioid radiation patterns over a large frequency range. In addition, the impedance behavior of the antenna should be such as to introduce a standing-wave ratio of no more than 2:1 over the frequency range. The impedance behavior of the antenna is not being investigated to the same extent as the radiation properties. The reason for this is that the same techniques developed for the omni-directional antenna can be used.

The work completed up to this report lead to the following observations:

a). An antenna half-filled with paraffin (relative dielectric constant of 2.25) and half-filled with Hexcel (a honeycomb type plastic which is mechanically strong and has a dielectric constant very close to that of air) is satisfactory when tested as a model of scale factor of about 8.5 to 1.

b). The impedance behavior of the antennas under consideration can be improved by the use of a tuning condenser between the feed point and center-plate.

During the present quarterly period, a model half-filled with Hysol (a precast plastic of relative dielectric constant of about 3.0) was tested. This model improved the scaling factor (made the final full-scale model smaller) but showed a narrower band-width. An enlarged model (filled with paraffin with holes drilled in it so as to lower the dielectric constant from 2.25 to an average of 1.7) was tested. The radiation patterns were not substantially improved.

A large portion of the present quarterly period was spent in the investigation of the behavior of a coaxial line partially filled with dielectric. The guide wavelength in the coaxial line can be determined theoretically as a function of dielectric filling. This was verified by measurements. A better understanding of the properties of this line is necessary in the design of the cardioid pattern antenna, since it is the partially filled coaxial line which fixes the proper field in the radiating slot. It is planned to have this portion of the investigation appear as a separate laboratory report.

The plans for the final two months of this phase of the contract are as follows:

a. A larger model of the paraffin half-filled antenna will be tested to check the antenna described under (a) above.

b. A report summarizing all the previous work and giving recommendations for the design of the cardioid antenna will be written.

Semi-flush Mounted (Horn) Type

The completed full-scale model antenna for this part of the program is mounted on a quarter-inch dural plate approximately 60 x 70 inches. The working portion of the antenna has a maximum length of 48.6 inches, a maximum width of 42.6 inches and a maximum height of slightly under 7.0 inches overall. The top-plate is of 3/16 inch dural. The interior is entirely filled with Hexcel plastic honeycomb which is securely bonded to all metal surfaces. The entire upper surface is covered with a "skin" of glass cloth coated with several layers of EPON thermo-setting plastic, forming a very hard, strong, and abrasion-resistant surface. Electrical connection to the antenna is made with a standard type "N" connector at the rear so that the entire under surface of the antenna is flat and unobstructed. This feature is important in an antenna of this size since it is more easily handled with this construction and danger of damaging the r-f fitting is minimized.

Complete pattern and impedance data have been taken on the antenna at the Navy Electronics Laboratory in San Diego, and satisfactory results were obtained. The design is intended to have a SWR under 2.0 over the range from 225 to 400 mc. The flattest curve obtained was 2.8 at 225 mc, dropping very steeply to 1.6 at 235 mc and remaining under 1.75 out through 900 mc. A deep null occurs in the forward pattern between 800 and 900 mc so the investigation was not carried further. The SWR is actually below 1.5 at all frequencies above 300 mc.

Patternwise, the front-to-back ratio is of the order of 3 or 4 db at 225 mc, increasing rapidly with frequency. It is of the order of 15 or 20 db at all frequencies above 280 mc. The general character of the pattern is that of a cardioid, with a small amplitude, narrow back lobe. The forward radiation is nearly constant over a range from 150 to about 200 degrees, depending on frequency, and at vertical angles up to at least 60 degrees. To the rear the radiation drops very sharply. In the upper half of the band nearly all the radiation to the rear is concentrated in one or more minor lobes, most of which are at high vertical angles and are down 10 to 20 db from the main forward lobe. In compliance with the specifications, there are no null or even sharply defined minima at any frequency in the volume bounded by azimuth

angles of $\pm$ 75 degrees and a vertical angle of 60 degrees.

Impedance measurements and patterns were also taken for the case of the antenna placed on 5.5" wooden blocks (approximately deck thickness) over the ground plane, and also for the extreme case of the antenna placed on small saw-horses about 1 foot above the ground plane.

In the required band no important effect was observed on the antenna impedance in either case. The patterns were only slightly affected at the low frequency end of the range; the effect increasing for the larger antenna-to-ground-plane spacing.

Summary of results of tests of the horn-type antenna:

1. The horn-type antenna can be satisfactorily fabricated to meet all mechanical and electrical specifications except the requirement for flush-mounting. However, its vertical height of 7 inches is small.

2. It is found to have satisfactory electrical characteristics over a bandwidth nearly twice as great as that specified. Thus it may prove of value in other than the intended application, particularly when scaled to some other frequency range.

3. Its tolerance of separation from the ground plane should make field testing of its performance extremely simple. It may be simply placed on the deck of any ship in a reasonably clear position without cutting holes or doing other machine work.

4. Even better performance between 225 and 250 mc could be obtained by scaling the antenna about 10 per cent larger if this seemed desirable.

A complete technical report on this antenna is now being prepared.

7.3 Antenna Matching Investigations

The object of this part of the study is to see what can be done toward extending the useful operating ranges of circular slot antennas of given sizes by the use of input-impedance matching techniques. The work has been directed largely toward finding a general, practical method for synthesizing band-pass

-28-

matching networks. Though the work of Fano[1] gives considerable insight into the nature of this problem, his design methods are not particularly helpful for the class of band-pass matching networks under consideration.

The radiating-slot equivalent circuit mentioned in the last Quarterly Report is shown in Fig. 1. The problem under consideration is to find a
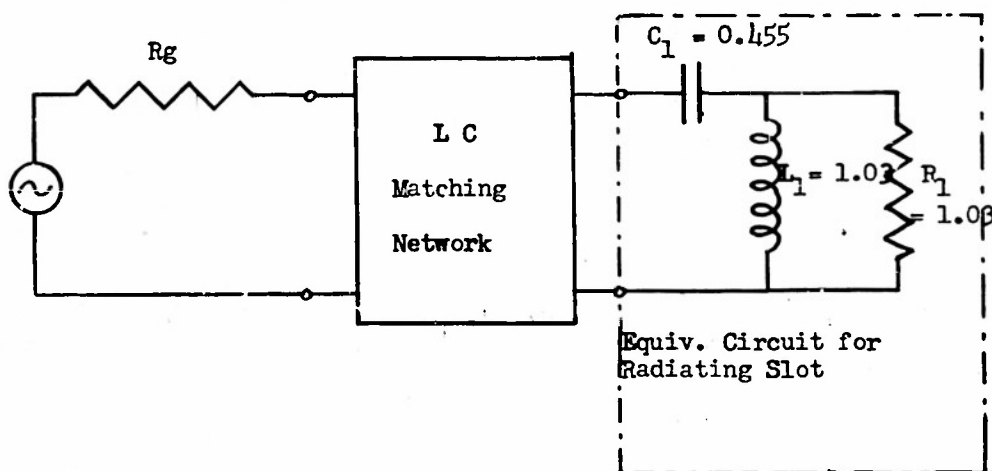

Fig. 1

matching network which satisfies the following conditions:

A. The standing-wave ratio is to be 1.75 or less throughout a pass-band having a band-edge ratio of 1.8.

B. The matching network design should locate this pass-band at the lowest frequencies possible for any given number of matching-network elements.

----
1. Fano, R.M., "Theoretical Limitations on the Broadband Matching of Arbitrary Impedances", Journal of the Franklin Institute, Vol. 249, January, pp. 57-84, Febraury, pp. 139-154, 1950.

Quite a few different design techniques have been experimented with. It has been found that the design approaches which are fruitful vary somewhat, depending on the ratio of C_1/L_1 corresponding to Fig. 1. The optimum design for a two-element matching-network is based on a transmission characteristic which is often rather difficult to pre-determine. If the ratio of C_1/L_1 were made large enough, the optimum two-element matching network design can be based on an equal-ripple transmission-function characteristic which is easily derived from a Chebyshef polynomial mapped by a low-pass to band-pass transformation. It is much easier to handle these cases where C_1/L_1 are large because it is easier to find an efficient and appropriate transmission characteristic. Unfortunately, the ratio C_1/L_1 = o.441 for the example in Fig. 1 is far too small to permit good results by use of standard Chebyshef characteristics,

Many avenues for further investigation have become evident from the work done during the summer on this problem. Since the CCA work is being brought to a close, a report will be prepared which will suggest, by an example, the order of magnitude of the performance improvement of circular slot antennas obtainable by simple matchine elements. Such improvement makes possible a decrease in antenna size (and weight) for given bandwidth and SWR specifications. This material will appear as part of a report on omni-directional annular slot antennas.

The research will be continued, shifting emphasis somewhat to the development of a generalized approach to the synthesis of matching network for broadband systems, and will be carried on in connection with other studies of broadband radiating systems and associated networks being done here.

VIII. BROADBAND RADIATING SYSTEMS AND ASSOCIATED NETWORKS AT MICROWAVE FREQUENCIES

Prof. D. J. Angelakos

H. A. Judy

8.1 General

The desirability of making use of one antenna-line system for more than one frequency range leads to this study. Such a system consists of the following basic parts:

a). Transmission line.

    1. The circular TE_{01} mode offers a possible solution.

    2. Multi-mode transmission systems. More than one mode of field configuration can exist in the same guide.

    3. The ridge-waveguide as a broadband line.

      The three types of transmission lines are being considered and their properties are being compared.

b). Antenna. The antenna behavior over the band of frequencies is to be investigated.

c). Components. Such components as matching sections, directional couplers, transition sections etc., will be individually investigated and designed.

    The directional coupler applied to multi-mode waveguide is being considered by a Research Assistant (see below). Another Research Assistant has just started a study of the use of ferrites as microwave component variables for application to this investigation.

<div align="right">D. J. Angelakos</div>

8.2 Multi-Mode Directional Couplers

A project has just been started to study and develop directional couplers in conjunction with rectangular waveguides propagating TE_{10} and TE_{20} modes.

The present emphasis is on mode-selective couplers which may be used as experimental equipment in future multi-mode studies. Coupling apertures in the narrow side of the waveguide have no intrinsic mode selectivity so

coupling will be confined to the broad side of the waveguide. Here, coupling apertures utilizing electric coupling have appreciable magnetic radiation which severely complicates the problem of mode selection. It is felt that the utilization of narrow slot magnetic coupling will facilitate the development of relatively simple coupling arrays. By placing narrow slots parallel to lines of current flow of one mode, while cutting lines of current flow of the other mode, each slot may be made intrinsically mode-selective and offer a minimum discontinuity to the undesired mode.

Various coupling schemes are under consideration. Those which seem most desirable will be built and studied, using two modes of propagation at the same frequency in waveguide with inside dimensions of 0.4" x 1.6".

H. A. Judy

IX. RELATED RESEARCH STUDIES

Contract Number

N7-onr-29529

Prof. L. J. Black
Prof. L. E. Reukema
Z. Kaprielian

J. Minushian
J. B. Humfeld
A. M. Serang

9.1 Metallic Delay Media -- Discs

Summary of Previous Work

This study is concerned with the electromagnetic propagation
characteristics of space arrays of aperture-in-metal discontinuities and
complementary structures. Design criteria for media of circular apertures
and discs for use as artificial dielectrics are considered. Using a
loaded transmission line analogy, with single mode interaction between
the elements, the susceptance of a sheet of apertures was calculated. By
direct application of Babinet's principle, the shunt reactance of a sheet
of discs was found. For disc diameters very small compared to transverse
spacing and for free-space wavelength very large compared to these spac-
ings the calculated index of refraction agrees with that based on a molec-
ular analogy first given by Koch (B.S.T.J. 1949). For larger apertures
and transverse spacing less than the wavelength, the results agree well
with experimental data on single sheets. The calculation of susceptance
has been done variationally and is valid for aperture diameter to trans-
verse spacing ratios up to 0.8, which considerably extends present design
limits.

A second method utilized the summation of scattered fields from a
semi-infinite array of obstacles. The amplitude of the far-zone scatter-
ed field yields knowledge of the bulk reflective properties. Specialized
to the case of small obstacles, an effective permittivity has been defined
based on the fact that the relative permeability is unity for normal in-
cidence.

Current Work

The experimental work, designed to measure the properties of an
infinite medium by a null method, and the phase shift of single sheets

by an additional method based on sheet separation for maximum transmission, has been continued. The null method of measurement was improved with respect to accuracy and reproducibility of data by using a more stable 3 cm. source and by adjusting the lengths of the free space and reference arms so that the frequency derivative of the phase difference is, on the average, zero with and without a sample in the free space arm. Antenna and sample interaction effects are compensated for by plotting phase shift against antenna to sample separation and taking the average value. With test slabs of Hysol, the index of refraction was measured to within one percent, most of the error being due to diffraction. Four types of media are being constructed, each consisting of 18 sheets of 18" x 18" alclad sheets 0.020" thick. Three are in a square pattern with aperture-to-wavelength spacings of approximately 0.15, 0.30 and 0.60, and a spacing-to-wavelength ratio of 0.85. The fourth is a rectangular pattern with aperture-to-wavelength ratio of 0.30. This perforated sheet medium has versatility in that, if irradiated from the edges, it serves as a parallel plate medium with periodic slots in the walls. A fifth medium, an exact complement of one of the square aperture patterns, is also being constructed by hot pressing discs on polyfoam. Such sheets will also be used to investigate a doubly periodic structure of apertures and complements.

<div align="right">J. Munushian</div>

9.2 Artificial Dielectrics – Rods

Summary of Previous Work

This study is of the dielectric properties of a medium consisting of a series of plane grids of conducting rods, for electromagnetic plane waves, with the polarization vector parallel to and perpendicular to the axis of rods. Dependence of the dielectric properties on rod diameter, spacing, and grid separation, are being studied.

For H-polarization, a zero order approximation has been calculated for isolated rods. This result was extended to account for dipole interaction between elements of the array and leads to a two-dimensional

Clausius-Mossotti relation for the electric polarizability. In addition, for both polarizations, the impedance of the planar grid has been calculated and used in an equivalent loaded transmission line as a first order approximation for the propagation constant and impedance.

For $Ka < 1$, which is the region of engineering interest, a method was developed which includes effects of interaction for the time-varying field and is based on summations of scattered fields. A special case of this result ($Ka << 1$) was found to be in agreement with results of Slater's cellular method for the same range of the variable Ka. For this same region, an equivalent permittivity and permeability can be defined for the medium.

To generlize formally the results for all values of Ka and spacings, the variational method used in quantum mechanics of crystals was reformulated from an integral equation point of view, thus replacing the problem of choosing trial wave functions with that of choosing trial values of the currents on the obstacles at the lattice points. This method would be particularly useful when the obstacles are of such a shape that the wave functions are not known.

Experimental equipment has been set up, consisting of a section of 10 cm. waveguide in which is an array of copper rods parallel to the broad faces. An almost continuous variation of spacing between the rods is possible. The index of refraction was found in the same way as for solid dielectrics. Within the range of guide wavelength, 10-20 cm., the index of refraction is constant with respect to wavelength within the accuracy of the measurement procedures. In general, agreement with theory has been good.

Current Work

Using similar variational techniques, a characteristic impedance was evaluated for the various transmission modes in the lattice, which in combination with the previous computation for the propagation constant in an infinite lattice, completely characterize the semi-infinite lattice for normal incidence. The solutions within the semi-infinite medium are represented as a superposition of various modes. Depending on the relationship of the lattice dimensions to the free-space wavelength, a given number of the induced modes will actually propagate energy through the

lattice. For certain ranges of Ka, as mentioned above, the equivalent medium description is valid. For the region of Ka where the higher modes can propagate, the bandpass filter characteristic of the medium is determined, with stop bands corresponding to large reflections and high attenuation, and with pass bands corresponding to the frequencies that can propagate. In the determination of the characteristic impedance, the trial current used was that of an isolated cylinder due to an incident plane wave multiplied by a phase factor which is a function of the direction of propagation and an exponential decay factor to take care of the transition region.

A free-space experiment was required to measure the characteristics for E-polarization, since this does not represent an infinite array if used in a wave-guide. A structure using lucite sheets perforated with 1/16 inch and 1/8 inch holes is being constructed to support the rods. The free space interferometer, using a null method, will be employed. This can also be used for comparison with the waveguide method for H-polarization.

<div align="right">Z. Kaprielian</div>

9.3 Analysis of the Side-Outlet Tee for Impedance Measurements

Summary of Previous Work

This study is of the use of a side-outlet tee as an impedance bridge at microwave frequencies. The errors introduced depend on the degree of matching of the tee, the extent to which the measurement is frequency sensitive, and the magnitude and phase of the coefficient of reflection from the test load.

In order to measure the sensitivity of the side-outlet tee to either the phase or the magnitude of reflection from a test load, a test load was devised such that its reflection coefficient could be varied in magnitude or phase, each independently. This load consisted of a Sperry transformer, a slide-screw tuner and a resistive load connected in tandem. This load was calibrated.

Current Work

A theoretical analysis of an asymmetrical tee was made. This analysis showed that the sensitivity of the tee to the phase of the test load reflection was due to the asymmetric coupling between the E- and H-arms, as well as the mismatch seen looking into the junction through the test arm. Further analysis established the theoretical relationships between the coupling and reflection coefficients of junction arms and the phase and magnitude of reflection from the test load. From this analysis it was possible to devise means of removing the errors due to asymmetry and mismatch. These means were proven to be correct both by theoretical analysis and experimental work.

The means of removing errors, in impedance measurements, due to asymmetric cross-coupling and mismatch were as follows:

1) Using the H-arm of the tee as the input arm, the E-arm was coupled to a detector and the side arms to matched loads. If the tee had been symmetrical there would have been no power delivered to the detector. However, the tee was asymmetrical and therefore there was coupling between the H- and E-arms. In order to eliminate this, the load on the reference side arm was tuned until the E-arm detector received as little power as possible. In this way, the load on the reference arm was no longer a matched load, but it produced a desirable minimum coupling between the input H-arm and the detecting E-arm. It was found possible to reduce the power delivered to the detector 65 to 70 db. below the input level. This, essentially, decoupled the E-arm from the H-arm.

2) With the test arm as the input arm, the reference load remaining as above, and a matched load coupled to the H-arm, the detector on the E-arm was tuned so that a match was seen looking into the junction through the test arm.

These two procedures eliminated the sensitivity of the tee to the phase of the test load reflection. Experimental measurements were made with loads of the following three kinds:

1) Two loads having reflection coefficients of constant magnitudes (VSWR = 1.68 and 1.17), but varying phase.

2) A load having a reflection coefficient of constant phase but varying magnitude.

-37-

3) A load having a reflection coefficient which varied both in phase and magnitude.

The experimental measurements were made with the H-arm used as the input arm, the reference arm carrying the tuned reference load, the E-arm coupled to the tuned detector and the test arm coupled to the loads mentioned above. The measurements showed that the output to the detector was independent of the phase of the loads. The VSWR's measured with the tee were within 5% of those measured with a slotted line. This result substantiated, experimentally, the theoretical analysis which suggested the method of tee alignment described above. Thus the constructional asymmetry and mismatch conditions in a side-outlet tee can be compensated for in such a way that the tee is insensitive to the phase of the reflection from the test load. The experimental results also verified the theoretical expectations that the power delivered to the detector is proportional to the square of the magnitude of the test load reflection. Thus a side-outlet tee can be easily calibrated, at one frequency, to use for direct measurement of the VSWR of any unknown load.

The side-outlet tee was tuned at 9440 mcs. with slide-screw tuners which were coupled to the necessary arms of the tee. These tuning elements made the tee extremely frequency sensitive. The effect of frequency variation was measured and it was found that for a frequency shift of $\pm$ 80 mc, the decoupling which was achieved between the input H-arm and the output E-arm was reduced from - 70 dbs to - 35 dbs. The VSWR seen looking into the test arm was increased from 1.02 to 1.5. This extreme sensitivity to frequency is probably due to the fact that the reactive tuning elements were not placed at the junction proper, and that these elements are themselves frequency sensitive. Thus a tee aligned and matched by use of slide-screw tuners is suitable for use as an impedance bridge for only a small frequency band-width. Furthur investigation may lead to the devising of tuning techniques which would enable the use of such a tee at more than a narrow frequency band width. A report on this study is being prepared.

A. M. Serang

9.4 Loaded Whip Antenna

Summary of Previous Work

This is a design and performance study of a 2-30 mc whip antenna with a high-efficiency, variable inductance as the loading element. This specially-designed element can be placed at any desired position on the whip, and can be tuned either manually or automatically, from a frequency control unit at the base of the antenna. In order that data might be obtained on mutual coupling characteristics, two such antennas have been designed and built.

Current Work

Tests were conducted at the Navy Electronics Laboratory at San Diego to obtain base impedance and radiation characteristics. The antennas were found to tune to odd multiples of a quarter wave length over the band of 2 - 30 mcs. Impedance data, as a function of frequency about resonance for a given setting of the variable inductor, were also compiled for various resonant frequencies. The Q's of the antennas were measured at 2 mc. by a frequency deviation method. The expression is

$$Q_{\frac{n\lambda}{4}} = \frac{f_{n \lambda/4}}{\Delta f}$$

in which

$f_{\frac{n\lambda}{4}}$ = is the quarter or three-quarter wave resonance frequency depending on the value of loading coil inductance (i.e., n = 1,3)

Δf = difference between the two half-power input frequencies as determined by impedance measurements.

These Q's were found to be in the neighborhood of 400 at 2 mc, thus indicating promise in off-frequency signal rejection when the antenna is used in receiving applications.

An attempt was made to measure vertical radiation patterns, but without success. This was due largely to the small size of the available

ground plane and limited vertical pattern measuring facilities. The "small
size" is inferred by the fact that to exclude near zone field effects from
the measurements, one would have to be 6 to 10 wavelengths from the antenna
under test—which would mean a separation of at least a half-mile at the low-
est frequency involved. The difficulties in obtaining vertical pattern
measurements are obvious.

The antennas exhibited excellent power feeding characteristics, a
voltage of only 170 volts being required to feed 100 watts at 2 mc into the
base of the antenna from a 50 ohm source, whereas approximately 11,000 volts
would be required to feed 100 watts into an unloaded vertical antenna of
the same height under the same conditions.

An attempt to measure the radiated power is planned by the method of
calculating the vertical field pattern, obtaining absolute field strength
measurements along the ground plane under satisfactory conditions, and then
determining the power radiated by the Poynting Vector graphical method.
The input power may be easily measured and thus yield the efficiency of the
antenna.

J. B. Humfeld

X. ADMINISTRATION

In connection with work under contract numbers W33(038)-ac-16649 and AF33(616)-495 Mr. W. Nelson of Wright Air Development Center visited this Laboratory.   In connection with work under Contract N7-onr-29529 Mr. E. L. Johnston of the Bureau of Ships, and Mr. A Shostak and Dr. E. R. Piore of Office of the Naval Research were here.

XI. REPORTS, PAPERS, AND TALKS

11.1 REPORTS ISSUED:

G. Held and W. Kummer, "Obstacles and Discontinuities in a Multimode
Waveguide", University of California Electronics Research Laboratory Technical Report, Series NO. 60,
Issue NO. 101. (Contract N7-onr-29529)

11.2 PAPERS PRESENTED:

G. Held,   "The Generation of Electromagnetic Oscillations in the
Microwave Region Using an Adiabatic Kind of Amplification", presented to the I. R. E. Western Convention,
San Francisco, California, August 20, 1953

S. V. Yadavalli, "Convection Current Noise—Theory and Experiment",
presented to the I. R. E. Western Convention, San Francisco, California, August 19, 1953

11.3 REPRINTS:

S. Silver,   "Diffraction of Microwaves by Apertures and Obstacles",
Supplemento al Nuovo Cimento, 9, 401-408, 1952

M. Currie,   "The Utilization of Degenerate Modes in a Spherical
Cavity". Journal of Applied Physics Vol. 24, NO. 8, 998-
1003, August 1953

DISTRIBUTION LIST

Organization	No. of Copies
Bureau of Ships (Code 838)	5
Cambridge Air Research Center	3
Chief of Naval Research (Code 427)	5
Havard University	1
Massachusetts Institute of Technology	1
Office of Naval Research, San Francisco	2
Rome Air Development Center	2
U. S. Navy Electronics Laboratory, San Diego	1
Wright Air Development Center (MCREES 23)	50

Armed Services Technical Information Agency

AD 41256

UNCLASSIFIED